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Reactive Power Pricing Simultaneous Using Spot and Bilateral Market Models Considering Opportunity Cost

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Abstract

Reactive power as a utility of ancillary service in restructured environment is supplied by Independent System Operator (ISO). Due to the particular importance of optimal pricing strategy in the power market, the study aims to investigate this problem more closely. To this end, first the problems of restructuring, reactive power generation and its associated costs thereof were reviewed and different types of transmission rights identified. Next, an algorithm was proposed as the selected method for reactive power pricing in terms of Fina g simultaneous Opportunity Cost (OC) at power plants. The pricing method was based on the respective marginal costs as ncial Transmission Rights (FTR) of transmission lines in the presence of the hybrid market model (spot and bilateral) usin well as the optimal power flow and implemented the succession planning method via MATLAB for IEEE 57-buses test system. Comparison of the results obtained from the proposed method (where in capacitors and Static VAR Compensator (SVC) were considered as reactive power generation sources) with those of the current pricing method used in the Iran power grid showed increased earnings due to reactive power investment.

Keywords: Open Access, Electric Power Transit, Reactive Power Pricing, Financial Transmission Rights (FTR)
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1. Introduction

The power industry has been recognized as a most effective factor on economic growth, development, and social welfare in recent years, and is on its way to becoming a competitive and distributed industry where market powers determine prices and the net cost are reduced via increased competition.

Power markets are divided in terms of such factors as competition, exchange and time type. The power market is in turn divided into energy markets, ancillary services and transmission market based on the type of transaction. Ancillary services are required to ensure the correct grid performance and include the following:

- Operation control
- Voltage and reactive power control
- Frequency control and adjustment
- Commissioning power grid
- Energy imbalance
- Backup reserve (spinning and non-spinning)

Due to the close relationship between voltage amplitude and reactive power in power system, the latter plays an effective role in the power system security since reactive power is an instrument for maintaining the desired voltage profile. In general, reactive power backup should meet the following system requirements:

- Responding continuously to the reactive power needs of the both system and the customers
- Maintaining the system voltage within an acceptable range
- Providing sufficient reserve to respond to reactive power variations which might occur during emergency situations and maintain the system security and quality criteria under such conditions
- Optimizing system losses

In this study, the role of reactive power in maintaining the system voltage within specific limits during steady state and transient was considered. Reactive power resources and equipment are required for providing static and dynamic backup to respond to customers' needs, cover reactive power losses in transmission and distribution systems, and maintain proper voltage backup and control. These resources are essential for preventing unbalance and voltage collapse in the system during emergency situations.

Section 1 addresses certain topics related to reactive power pricing and the research hereof. Section 2 discusses the implemented mathematical model, and Section 3 describes the implementation of this model in the IEEE 57-buses test system as well as the obtained results.

Transmission costs are financed via the following methods:

- contract path
- postage stamp
- MW-mile
- Pricing based on flow direction

Transmission rights can be obtained in the following transmission markets: annual auctions markets, monthly auction markets, and secondary markets. These rights are divided into the following groups:

- Physical Transmission Rights (PTR) where a specific capacity is determined for each grid element and simultaneously allocated to the producer and consumer of these rights. In certain markets, these rights are transferrable.
- Financial Transmission Rights (FTR): financial instruments which protect the applicants against increased costs resulting from transmission congestion on the condition that their energy consumption shall not exceed a previously agreed capacity.

Since reactive power backup is crucial due to its effect on the power system security, specific procedures are required to guarantee proper reactive power backup for the power system. To this end, fair pricing policies must be followed practiced. The prerequisite for this is a close investigation of the costs associated with reactive power. Today, development of detailed methods for reactive power pricing in the power market is of particular importance. The price of reactive power cannot be obtained through traditional load flow models since these models do not take into account reactive power generations costs. In restructured power markets, reactive power pricing process is a complicated problem and therefore developing a proper reactive power pricing structure is of particular significance in terms of financial and operation aspects of the system. In this regard, analysis of the costs associated with reactive power is an inevitable activity and pricing must be based on such analyses. The fundamental features of reactive power pricing are:

- Providing fair earnings for providers of reactive power (including proper cover for costs as well as appropriate returns)
- Motivating consumers of reactive power through various incentives to use it optimally and correctly.

Reactive power Pricing is based on the following methods:

- Determining the actual real-time reactive power service with due attention to optimal voltage stability and profile in the open access power industry
- Reactive power pricing using opportunity costs
- Reactive power pricing in terms of FTR’s transmission lines

While possessing the advantages of other methods, reactive power pricing based on FTR’s transmission lines also takes into account the limitations associated with power transmission through transmission lines. In [1], having enough reactive power is a necessity for a reliable, safe, and robust electrical network. Producing units would be convinced to produce reactive power only if an appropriate pricing strategy is implemented by the system. The price proposition structure for reactive power production is modified through this study in order to create more fair competition in this market. This new structure is represented on a 24-bus IEEE RTS network. On the other hand, reactive power market has been held simultaneously with energy market, since active power and reactive power are related to each other. Moreover, a new structure is presented here to calculate ‘LOCs’ in reactive and active power markets. The results show that reactive and active power components produced by a number Of units enter the opportunity zone and impose higher operating costs to the network. Considering that structure of LOC payment is integrated into objective function of optimization problem in SARPM, it would be minimised through market solution. Therefore, using SARPM leads to lower amount of LOCs, hence leading to a better solution for the system. Moreover, the SARPM model is presented as a region-based model in order to account for Regional nature of reactive power. It was observed that considering local nature of reactive power, the simultaneous market structure proposed in this study has led to a decrease of operating costs while improving reactive power production practices. In [2], we propose a Reactive Pricing (RP) algorithm for the cloud provider to determine the spot server price in response to workload, renewable energy, and power price change. The advantages of RP are its simple structure and no requirement of a priori statistic information of exogenous random variables. It is shown by the theoretical analysis and numerical evaluation that RP achieves an [O(1/V),O(V)] performance-battery tradeoff. In our future works we will extend the model into a multiple geo-distributed data centers scenario to investigate a more general form of dynamic pricing strategy. In [3], proposes the integration of an enhanced version of a practical and transparent nodal reactive power pricing mechanism into the short-term operation of a DisCo considering a probabilistic approach. In the proposed approach, the cost of reactive power is fairly calculated for each consumer and DG unit as a function of their reactive nodal injections. Numerical results show that the DisCo's operation is significantly affected by the incorporation of the proposed reactive power pricing scheme. Indeed, the DisCo may increase its profits due to charges imposed to consumers with poor power factor. It also leads to increased network's active line losses because the DisCo seeks to perform the reactive control offered by the DG units at minimum cost. In addition, greater losses would be achieved while higher acceptable power factor limits for consumers are enforced. However, one of the main benefits from reactive pricing is that consumers would be encouraged to improve their power factor, which would drastically improve the network's efficiency. Further work will be devoted to exploring the following avenues of research:

- Contingency analysis of critical infrastructure of the distribution network.
- Integration of plug-in hybrid electric vehicles and dropcontrolled distributed energy resources into the shortterm operation planning of the DisCo.
- Application of the proposed custom reactive power pricing scheme to transmission systems.
- The proposed pricing scheme may be incorporated into an ac optimal power flow formulation.
- Use of network reduction approaches and parallel programming in order to better scale for real-life distribution networks.
- Between generators and consumers, retailers or distribution companies are allowed, the following conclusions can be obtained:
- Total generation cost will be always equal or higher if the generation-grid system allows power purchase agreements than the total cost obtained in the case these contracts do not exist, under the supposition that generation costs do not vary.
- Both total cost and spot prices can be influenced by power purchase agreements between suppliers and consumers. The difference is due to transmission cost induced and activation of new generation constraints. The stronger the activated constraints are the higher the difference will be.
- If two consumers are connected in the same node and they have power purchase agreements signed with different generation groups, their spot prices could be different. The difference is due to the introduction of generation constraints of these groups.
- The fact that a generator is producing only the active or reactive energy committed in its agreements, would be an indication of the influence of power purchase agreements on both total cost and spot prices.

For example, if it is generating only the reactive energy committed in its contracts, variation in spot price and total cost will be low. The more activated constraints are – due to power purchase agreements – the higher variation will be in prices. Once we have analyzed the influence that contractual relationships have on market results for every agent, it can be stated that these relationships should be analyzed before they are signed, not only to assure its technical feasibility but also to avoid disturbances in price formation that could affect transparency and correct competition performance in market.

In [5], a day price based reactive power planning algorithm is proposed. The basic objective of day ahead cost based reactive power dispatch is to reduce the cost of reactive power generation from generators and other VAr sources when generators are engaged in feeding a projected MW demand over a period of time. The proposed method is formulated to pay opportunity cost along with VAr supply cost of thermal generators. Moreover, the method recovers the investment cost and pays the operational cost of SC. The payment towards operational cost of reactive ancillary services is proposed to be sensitive to marginal price. To implement the PORPD approach, a marginal price based VAr response algorithm is developed and presented. The proposed model is implemented on standard IEEE test systems and results are verified under varied network conditions. This model provides a guideline for the ISO on how to operate the reactive ancillary services under dynamic market conditions. From the numerical analysis, following conclusions are drawn.

- The presence of reactive ancillary services in power system helps in reducing the overall reactive power generation cost of central generators.
- The proposed pricing approach encourages the reactive ancillary services to participate in the market more actively by supplying additional

reactive energy during higher demand hours and vice versa. Such approach would cause more operational gain for both the VAr supplier and central generators.

- During lower market price periods, there is possibility that the reactive ancillary services would not be interested enough to contribute more. As a result, the overall reactive power generation cost of central generators would thus increase.
- The performance of reactive ancillary services under market environment is sensitive to change in load characteristics.
- The proposed approach encourages the reactive ancillary services to be proactive in supplying reactive power when practical nonlinear voltage dependent loads exist in power systems. Such action would result savings on overall reactive power generation cost.

In [6], Market Center concept is a unique reference for delivery/withdrawal point for reactive power which is used to share the total transmission loss equitably between the GENCO and DISCO participants in a transparent manner for pure Q Market using incremental loss factor method. This model uses a slack bus independent loss factors measured with respect to ‘‘Market Center”. The contribution of the paper is the development of a new Optimal Reactive Flow Method (OQF) which can be used for market clearing and settlement of pure reactive power market. A lumped linear model is proposed for power balance equality constraint for fast convergence. The accuracy of voltage magnitude given by Iterative QF method is adequate for pure Q market. The validity of the proposed method was tested using three different systems viz: Radial Five Bus System, Ward and Hale 6 Bus System and IEEE 30 Bus System. For the Radial Five bus system, in the existing method, the GENCO is overcompensated by 0.064% and the price paid by the DISCO is 0.765% more when compared to the proposed method without violating voltage limits. The results of the proposed method indicate equitable loss allocation and market clearing and settlement.

The proposed OQF method uses loss factors which contributed the loss by each participant, independent of the marginal bus and recovers the actual loss cost from the participants. In the proposed method it is observed that the total bus loss is reduced by 20.2% for IEEE 30 Bus System thereby minimizing the cost of the objective function a detailed power flow model using the concept of power factor and physical location was introduced in [7]. This model was used based on FTR and LMP. In [8], two optimization sub problems were used for active and reactive power pricing. The objective function in this case was reactive power pricing along with minimizing active power generation. In the described states, the objective function was formed based solely on active power costs without accounting for reactive power costs. In [9], the safety constraints in the power system are used for optimal power flow using the equations of state. The MVAr cost curves were used [9] for reactive power pricing. A solution was proposed based on financial compensation for backup reactive power, opportunity costs of generators, and replanning for minimum payment by ISO for costs arising due to external constraints of the system [10]. Since increased demand and shortage of reactive power lead to voltage instability, increased losses, and consequently, more payments by ISO to production units, the Group Search Optimization (GSO) algorithm was used to minimize total cost as well as losses in the system through reactive power pricing [11]. The reactive power pricing based on marginal costs theory was used to motivate producers for participating in reactive power generation through implementing the reactive optimal power flow method [12]. In [14], a quadratic function was used for modeling reactive power cost for each generator in the reactive power generation minimization problem without offering a clear definition for reactive power cost curves. Baugham et al. presented relations based on the final cost theory introduced in [13, 14] for a modified power flow problem which used active power balance equations for simultaneous reactive power pricing. In [15], due to the importance of reactive power in voltage stability and profile, real-time reactive power pricing was investigated aimed at achieving in open access power grid the best voltage stability and profile simultaneously at minimized costs. In this regard, the Extended Multi-objective Optimal Power Flow (EMOPF) problem was presented and the Lexico Graphic Method (LGM) was used to solve this problem. The concept of marginal costs was used for real-time reactive power pricing service, and the effects of the desired voltage stability and profile were demonstrated. In [16-17], a solution was proposed for reactive power resource adjustment in the presence of bilateral power market, aimed at minimizing reactive power losses and optimizing voltage profile in the system as well as increasing grid stability. The general assumption here is that reactive power sources either belong to ISO or are under long-term contracts with the same. The EMOPF optimization problem was studied using the LGM method. Then, the Fair Resource Allocation (FRA) was used to allocate reactive power costs to the existing equations. In spite of the fact that no fuel is used for reactive power generating and considering that a cost function cannot be easily assigned to reactive power, reactive power generation nevertheless increases losses (lower useful life of generators) and ultimately increases fuel consumption. Reactive power pricing has been based on classifying buses which possess system generator and inter-area line connections by calculating and and including social welfare indexes [18]. In [19], a method is proposed for determining variable reactive power generation costs in generators via including numerous reactive power generation cost sections (fixed and variable costs as well as opportunity cost). This study investigated reactive power generation cost through the variable costs perspectives for the purpose of participation in the reactive power market. The generator operation cost function and reactive power generation cost were simultaneously optimized without allocating any fixed cost for reactive power [20]. The SALIN method was proposed for maintaining system security based on the optimal power flow through allocating an appropriate interval for the weight coefficient. Through this interval, pricing is conducted with good accuracy and social welfare as well as distance to voltage collapse is maximized [21]. Reactive power pricing policies in India were investigated where the pricing is based on penalty coefficient and duties [22]. Since LMP is composed of three components: energy, congestion and losses to including overall security level consists of an additional risk component in electricity market clearing mechanism called Risk-based Locational Marginal Pricing (RLMPs). Resulting RLMPs differ from conventional LMPs in that RLMPs provide an additional price signal reflecting the impact of change in nodal injections on the system risk level. In both cases, the RLMPs across buses were more tightly distributed than the LMPs suggesting that use of RLMPs may decrease volatility through time. The approach avoids the effect of price-penalties on price spikes while providing control to enhance the system security level [23].

2. Reactive Power Pricing Mathematical Model

In this paper, it is assumed that the demanded active and reactive power is specified via load flow prediction and that the optimum load flow remains constant throughout the problem. The purpose is to obtain the optimum active and reactive power generated via generation units so as to minimize the final operation cost and to optimize buses voltages so that the reactive power system losses would be minimized. It is assumed that minimizing system loss cost is equivalent to minimizing the reactive power cost in generators. Therefore, the objective function is:

$$C = \sum_{i=1}^{NG} \left[C_i \left(P_{G_i} \right) \right] \quad (1)$$

N_G represents the number of generators and $C_i(P_{G_i})$ is the reactive power generation cost function at Bus i. The active power generation cost function (the first term in Equation 1) is a quadratic function expressed as:

$$C_i \left(P_{G_i} \right) = a + bP_{Gi} + cP_{Gi}^2 \quad (2)$$

The Optimal Power Flow Problem with multiple constraints faced, continue to investigate some of these limitations are discussed.

Load flow equations: The following equations are derived from Kirchhoff's laws for describing load flow throughout the system:

$$\begin{aligned} &P_{Gi} - P_{di} - \sum_{j=1}^{Ni} |U_i||U_j||Y_{ij}|.Cos\left(\theta_{ij} + \delta_j - \delta i\right) = 0 \\ &Q_{Gi} - Q_{di} - \sum_{j=1}^{Ni} |U_i||U_j||Y_{ij}|.Sin\left(\theta_{ij} + \delta_j - \delta i\right) = 0 \end{aligned} \quad (3)$$

N_i is the number of the buses in the system. The above equations are used for active and reactive power respectively.

Power generation limitation: due to technical and economic reasons, every grid has a limited generation capacity. These limitations play a significant role in determining the working point as well as generation marginal costs. Generation limitations are generally expressed in terms of the maximum and minimum active and reactive power generation.

$$\begin{aligned} &P_{Gi,min} \le P_{Gi} \le P_{Gi,max} \\ &Q_{Gi,min} \le Q_{Gi} \le Q_{Gi,max} \end{aligned} \quad (4)$$

$P_{Gi,min}$ and $P_{Gi,max}$ are the minimum and maximum active power, and $Q_{Gi,min}$ and $Q_{Gi,max}$ are the minimum and maximum reactive power generated at the i-th bus. If the grid can generate only reactive power at the i-th bus, then the generation limitation constraint at the i-th bus is summarized as:

$$0 \le Q_{Gi} \le Q_{Gi,max} \quad (5)$$

Power transmission limitation: Power transmission limitations go back to the maximum power or current which can be transmitted under various conditions. These limitations are included based on thermal and dynamic stability considerations (for long and short transmission lines respectively). Following equation expresses the thermal limitation imposed on the maximum and minimum power flowing through transmission lines:

$$P_{ij,min} \le P_{ij} \le P_{ij,max} \quad (6)$$

$P_{ij,min}$ and $P_{Gi,max}$ are the minimum and maximum transmittable power respectively which can be transmitted via the lines between Bus i and Bus j. P_{ij} is calculated from the following relation:

$$P_{ij} = V_i V_j Y_{ij}.Cos\left(\theta_{ij} + \delta_j - \delta_i\right) - V_i^2 Y_{ij}.Cos\,\theta_{ij} \quad (7)$$

In this equation, shunt admittance is assumed to be negligible. In case the above range is exceeded, transmission congestion occurs which can endanger safety of the grid under steady state conditions. Since the FTR calculation method was adopted for reactive power pricing (because it includes congestion in the pricing process), the following equation is used for calculating FTR via LMP:

$$FTR = P_{ij}\left(LMP_{Pj} - LMP_{Pi}\right) \quad (8)$$

Transmission stability limitation: This is expressed as:

$$\delta_{ij,min} \le \delta_i - \delta_j \le \delta_{ij,max} \quad (9)$$

Voltage limitation: Voltage limitation entails limiting voltage amplitude to a small interval. Basically, voltage affects reactive load flow and reactive power cost limits at a bus are directly dependent on the equipment voltage level at that bus.

$$V_{ij,min} \le V_i \le V_{ij,max} \quad (10)$$

$V_{ij,min}$ and $V_{ij,max}$ are the minimum and maximum voltage at the i-th bus. To maintain voltage within the above interval, reactive power generation sources in the grid must be utilized.

The optimal power flow problem is a nonlinear optimization problem the objective of which is minimizing the cost function through satisfying equal and unequal system constraints. In a way, the optimization problem with constraints can be shown in the form of the following equation:

$$\begin{aligned} &minimize\ f(u,x) \\ &g(u,x) = 0 \\ &h(u,x) > 0 \end{aligned} \quad (11)$$

Functions g and h represent equal and unequal constraints respectively. Moreover, variables u and x are controllable and dependent system variables respectively.

The assumed mutual contracts are shown in Table 1.

Opportunity Cost: If, in the technical-economic layout, a unit suffers a reduction in power generation (compared with the economic layout) due to the technical constraints imposed on the grid (or the unit), this condition is referred to as the OC Opportunity Cost (OC) situation [24, 25].

$$C_i\left(Q_{G_i}\right) = \left[C_i\left(S_{G_i,max}\right) - C_i\left(\sqrt{S_{G_i,max}^2 - Q_{G_i}^2}\right)\right].\mathrm{K} \quad (12)$$

Reactive power pricing in terms of FTR can be performed for each bus in the power system by calculating the Lagrange coefficients from the following equation:

$$\begin{aligned} &Min_x \sum_{i=1}^{x}\left[C_i\left(P_{gi}\right) + Cost(\mathrm{O.C})_{gi}\right] \\ &-\sum_{i=1}^{NI} LMP_{pi}\cdot\left(P_{gi} - P_{di} - P_{Bil_i} - \sum_{i=1}^{NI}|U_i|.|U_j||Y_{ij}|.\mathrm{Cos}\left(\theta_{ij} + \delta_j - \delta i\right)\right) \\ &-\sum_{i=1}^{NI} LMP_{qi}\cdot\left(Q_{gi} - Q_{di} - Q_{Bil_i} - \sum_{i=1}^{NI}|U_i|.|U_j||Y_{ij}|.Sin\left(\theta_{ij} + \delta_j - \delta i\right)\right) \\ &-\sum_{i=1}^{NI} U_i^{\min}.\left(|U_i| - U_i^{\min}\right) + \sum_{i=1}^{NI} U_i^{\max}.\left(|U_i| - U_i^{\max}\right) \\ &-\sum_{i=1}^{NI} Q_i^{\min}.\left(Q_{gi} - Q_{gi}^{\min}\right) + \sum_{i=1}^{NG} Q_i^{\max}.\left(Q_{gi} - Q_{gi}^{\max}\right) \\ &-\sum_{i=1}^{NL}\sum_{j=1}^{NL}\gamma_{ij}^{\min}.\left(P_{ij} - P_{ij}^{\min}\right) + \sum_{i=1}^{NL}\sum_{j=1}^{NL}\gamma_{ij}^{\max}.\left(P_{ij} - P_{ij}^{\max}\right) \end{aligned} \quad (13)$$

Table.1.
Assumed bilateral contracts in standard IEEE 57-buses

Contract	*Seller*	*Buyer*	*Capacity (MW)*
1	Bus 8	Bus 9	40
2	Bus 12	Bus 16	20
3	Bus 12	Bus 17	20

3. Test System and its Results

To evaluate the above method for reactive power pricing, the IEEE 57-buses test system) was tested. The capacitor investment costs (in the form of capacitor banks) for purchasing, installing, and maintaining one MVAr and one SVC MVAr (based on thyristor and IGBT) were assumed to be 7207.82 and 130,000dollars respectively. All the costs were considered for an average life of 30 years. Iran's load duration curve was considered in the study (Fig. 2).

For comparison, the following pricing method studies were tested:

- Study 1: pricing based on the FTR's transmission lines
- Study 2: pricing based on the method used in Iran's transmission grid (coefficient of utilization: CU=0.7)
- Study 3: pricing based on the modified method in Iran's transmission grid (coefficient of utilization: CU=1)

In Iran's reactive power market, two payments are made to investing companies. The first payment is made for each MVAr-hour of electrical capacity (RCP or reactive capacity payment) provided by the contracting party and the other for each MVAr-hour of the supplied reactive power (REP or reactive energy payment). The utilization coefficient (measured as percentage of reactive capacity) was assumed to be 70%. Thus, the hourly rate of ready reactive power was assumed to be 6% of that obtained for active power in the electricity market [26]:

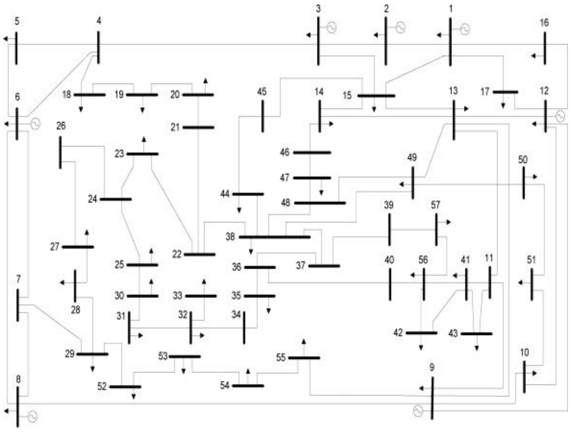

Fig. 1. IEEE 57-buses test system single line diagram

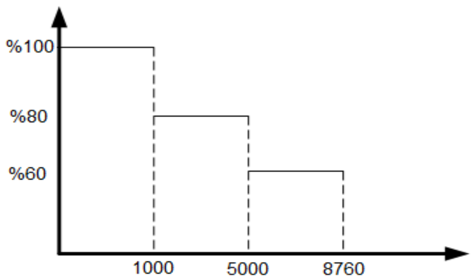

Fig. 2. California's load duration curve

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$$RCP = 57.81^{\left[\$/_{MW}\right]} \times 0.06 = 3.4686^{\left[\$/_{MVAr.h}\right]} \quad (14)$$

Similarly, the average reactive capacity payment is calculated from average power as:

$$REP = 138.75^{\left[\$/_{MW.h}\right]} \times 0.18 = 24.975^{\left[\$/_{MVAr.h}\right]} \quad (15)$$

The installed capacitors were considered based on the optimum power flow at the following buses: 19, 21, 24, and 25. Table 2. shows the results obtained from the above studies via MATLAB. C_F is the cost paid for compensatory investment, R_t is the overall income of the network, and $\%i$ is the Internal Rate of Return (IRR). Considering that the difference between FTR's grid before and after the compensator is large, we can conclude that losses have reduced after the compensator. With decreased losses, the nodes' LMP move closer together, i.e., their difference is reduced and this difference directly affects the FTR after the compensator.

Table.2.
Results obtained from the IEEE 57-buses test system studies (with capacitors and SVC assumed as sources of reactive power generation)

Bus	Parameter	Study#1		Study#2		Study#3	
		SVC	Capacitor	SVC	Capacitor	SVC	Capacitor
19	C_F [$]	96200	5.30×10^4	962000	5.3×10^4	962000	5.30×10^4
	R_t [$]	1.78×10^4	1.78×10^4	4.76×10^4	4.8×10^4	4.85×10^4	4.88×10^4
	$\%i$	-3.44	33.5	2.77	91.56	2.92	91.562
21	C_F [$]	96200	5.30	962000	5.30×10^4	96200	5.30×10^4
	R_t [$]	1.78×10^4	1.78×10^4	4.76×10^4	4.85×10^4	4.85×10^4	4.88×10^4
	$\%i$	-3.44	33.5	2.77	91.56	2.92	91.562
24	C_F [$]	96200	5.30×10^4	962000	5.30×10^4	96200	5.30×10^4
	R_t [$]	1.78×10^4	1.78×10^4	4.76×10^4	4.85×10^4	4.85×10^4	4.88×10^4
	$\%i$	-3.44	33.5	2.77	91.56	2.92	91.56
25	C_F [$]	96200	5.30×10^4	962000	5.30×10^4	96200	5.30×10^4
	R_t [$]	1.78×10^4	1.78×10^4	4.76×10^4	4.85×10^4	4.85×10^4	4.88×10^4
	$\%i$	-3.44	33.5	2.77	91.56	2.92	91.56

4. Conclusion

A new Security Constrained Unit Commitment (SCUC) solved by Mixed Integer Nonlinear Programming (MINLP) and Benders Decomposition was presented in this paper. Optimum solution satisfies the network constraints and minimizes the objective function that is minimum total cost considering maximum reliability, on the other hand we used interface between GAMS and MATLAB to solve this problem. In this paper we used Expected Energy Not Served (EENS) and Loss of Load Probability (LOLP) as reliability indexes. Results on IEEE 57 and 118-bus as test systems and comparison showed good efficient of this propose method.

Reactive power pricing (with capacitors and SVC as sources of reactive power generation) was conducted in this article fort earning higher incomes for the investing company. The results obtained via simultaneous application of bilateral contracts and opportunity cost showed that, as compared with the current method implemented in Iran's power grid, using the FTR method by the investing company for reactive power pricing would earn higher incomes for the investing company.

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Nomenclature

NL	Number of Lines	$C_i\left(P_{gi}\right)$	Cost of Active Power Generation at Bus i
i, j	Bus Index	$FTR_{peak\,x(i,t)}$	Financial Transmission Rights of Peak Load before Compensation for Line i at hour t
NG	Number of Generation Units	$FTR_{offpeak\,x(i,t)}$	Financial Transmission Rights of Off-peak Load before Compensation for Line i at hour t
$Cost\left(O.C\right)_{gi}$	Opportunity Cost of Unit i	$FTR_{low\,x(i,t)}$	Financial Transmission Rights of Low Load before Compensation for Line i at hour t
P_{Bil_i}	Dispatchable of Active Power in Bilateral Contract	$FTR_{peak\,y(i,t)}$	Financial Transmission Rights of Peak Load after Compensation for Line i at hour t
Q_{Bil_i}	Dispatchable of Reactive Power in Bilateral Contract	$FTR_{offpeak\,y(i,t)}$	Financial Transmission Rights of Off-peak Load after Compensation for Line i at hour t
$\left\|U_i\right\|$	Voltage Amplitude at Bus i	$FTR_{low\,y(i,t)}$	Financial Transmission Rights of Low Load after Compensation for Line i at hour t
$U_i^{\min}$	Lower Limit Voltage at Bus i	$FTR_{Tpeak(t)}$	Difference of Power Grid Financial Transmission Rights of Peak Load at time t
$U_i^{\max}$	Upper Limit Voltage at Bus i	$FTR_{Toffpeak(t)}$	Difference of Power Grid Financial Transmission Rights of Off-peak Load at time t
$\left\|U_j\right\|$	Voltage Amplitude at Bus j	$FTR_{Tlow(t)}$	Difference of Power Grid Financial Transmission Rights of Low Load at time t
$U_j^{\min}$	Lower Limit Voltage at Bus j	FTR_{ij}	Multiplication between Difference of Local Marginal Price at Bus i,j and Active Power across between Bus i,j
$U_j^{\max}$	Upper Limit Voltage at Bus j	d_{peak}	Duration of Peak Load in year
$\gamma_{ij}^{\min}$	Minimum Marginal Cost between Bus i,j	$d_{offpeak}$	Duration of Off-peak Load in year
$\gamma_{ij}^{\max}$	Maximum Marginal Cost between Bus i,j	d_{low}	Duration of Low Load in year
δ_i	Voltage Phase at Bus i	T_{Tpeak}	Revenue of Peak Load
δ_j	Voltage Phase at Bus j	$T_{Toffpeak}$	Revenue of Off-peak Load
P_{gi}	Active Power Generation at Bus i	T_{Tlow}	Revenue of Low Load
$P_{gi}^{\min}$	Minimum Active Power Generation at Bus i	Q_{Tpeak}	Total Compensated Reactive Power of Peak Load
$P_{gi}^{\max}$	Maximum Active Power Generation at Bus i	$Q_{Toffpeak}$	Total Compensated Reactive Power of Off-peak Load
Q_{gi}	Reactive Power Generation at Bus i	Q_{Tlow}	Total Compensated Reactive Power of Low Load

$Q_{gi}^{\min}$	Minimum Reactive Power Generation at Bus i
$Q_{gi}^{\max}$	Maximum Reactive Power Generation at Bus i
P_{di}	Active Power Demand at Bus i
Q_{di}	Reactive Power Demand at Bus i
$\lvert Y_{ij} \rvert$	Admittance Amplitude of Lines between Bus i,j
θ_{ij}	Phase Angle of Lines between Bus i,j
$P_{i,j}$	Active Power across between Bus i,j
$P_{ij}^{\min}$	Minimum Active Power across between Bus i,j
$P_{ij}^{\max}$	Maximum Active Power across between Bus i,j
$P_i(\theta,U)$	Delivered Active Power depend on Voltage Amplitude and Phase Angle at Bus i
$Q_i(\theta,U)$	Delivered Reactive Power depend on Voltage Amplitude and Phase Angle at Bus i
$S_t(\theta,U)$	Apparent Power depend on Voltage Amplitude and Phase Angle at time t
$S_{\max}$	Maximum Apparent Power

R_{peak}	Revenue of Peak Load per Reactive Power
$R_{offpeak}$	Revenue of Off-peak Load per Reactive Power
R_{low}	Revenue of low Load per Reactive Power
$Q_{peak(j)}$	Reactive Power Generation in Company j of Peak Load
$Q_{offpeak(j)}$	Reactive Power Generation in Company j of Off-peak Load
$Q_{low(j)}$	Reactive Power Generation in Company j of Low Load
$R_{Tpeak(j)}$	Revenue of Company j of Peak Load
$R_{Toffpeak(j)}$	Revenue of Company j of Off-peak Load
$R_{Tlow(j)}$	Revenue of Company j of Low Load
$T_{T(j)}$	Total Revenue of Company j in year
LMP_{pi}	Local Marginal Price of Active Power at Bus i
LMP_{qi}	Local Marginal Price of Reactive Power at Bus i
LMP_{pj}	Local Marginal Price of Active Power at Bus j